Patent Application of

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for

Mode Lookup Tables for Data Transmission in Wireless Communication Channels Based on Statistical Parameters

RELATED APPLICATIONS

This application is a continuation-in-part to application serial number 09/665,149 filed on 9/19/2000.

FIELD OF THE INVENTION

The present invention relates generally to wireless communication systems and methods, and more particularly to the construction of mode lookup tables for encoding data for transmission in a wireless communication channel based on statistical parameters.

BACKGROUND OF THE INVENTION

Wireless communication systems serving stationary and mobile wireless subscribers are rapidly gaining popularity. Numerous system layouts and communications protocols have been developed to provide coverage in such wireless communication systems.

Wireless communications channels between transmit and receive devices are inherently variable and their quality fluctuates. Specifically, the quality parameters of such communications channels vary in time. Under good conditions wireless channels exhibit good communication parameters, e.g., large data capacity, high signal quality, high spectral efficiency and throughput. At these times significant amounts of data can be transmitted via the channel reliably. However, as the channel changes in time, the communication parameters also change. Under altered conditions former data rates, coding techniques and data formats may no longer be feasible. For example, when channel performance is degraded the transmitted data may experience excessive corruption yielding unacceptable communication parameters. For instance, transmitted data can exhibit excessive bit error rates or packet error rates. The degradation of the channel can be due to a multitude of factors such as general noise in the channel, multi-path fading, loss of line-of-sight path, excessive Co-Channel Interference (CCI) and other factors.

In mobile systems, signal degradation and corruption is chiefly due to interference from other cellular users within or near a given cell and multipath fading, in which the received amplitude and phase of a signal varies over time. The fading rate can reach as much as 200 Hz for a mobile user traveling at 60 mph at PCS frequencies of about 1.9 GHz. In such environments, the problem is to cleanly extract the signal of the user being

tracked from the collection of received noise, CCI, and desired signal portions.

In Fixed Wireless Access (FWA) systems, e.g., where the receiver remains stationary, signal fading rate is less than in mobile systems. In this case, the channel coherence time or the time during which the channel estimate remains stable is longer since the receiver does not move.

Prior art wireless systems have employed adaptive modulation of the transmitted signals with the use of feedback from the receiver as well as adaptive coding and receiver feedback to adapt data transmission to changing channel conditions. Such adaptive modulation is applied to Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO) systems, e.g., systems with antenna arrays at the transmit and receive ends.

In both SISO and MIMO systems, however, the fundamental problem of efficient choice of the mode to be applied to the transmitted data remains. For general prior art on the subject the reader is referred to A.J. Goldsmith et al., "Variable-rate variable power MQAM for fading channels", IEEE Transactions of Communications, Vol. 45, No. 10, Oct. 1997, pp. 1218-1230; P. Schramm et al., "Radio Interface of EDGE, a proposal for enhanced data rates in existing digital cellular systems", Proceedings IEEE 48th Vehicular Technology Conference (VTC' 1998), pp. 1064-1068; and Van Noblen et al., "An adaptive link protocol with enhanced data rates for GSM evolution", IEEE Personal Communications, February 1999, pp. 54-63.

U.S. Pat. No. 6,044,485 to Dent et al. teaches a transmission method and system which adapts the coding of data based on channel characteristics. The channel characteristics are obtained either from a channel estimation circuit of from an error feedback signal. In particular, when the signal-to-noise (SNR) characteristic is chosen as an indicator of the state of the channel, then a different coding is applied to the data being transmitted for high and low SNR states of the channel. In addition, the encoding also employs information derived from the cyclic redundancy check (CRC).

The method taught by Dent varies the coding rate only and not the modulation rate. This method does not permit one to select rapidly and efficiently from a large number of encoding modes to adapt to varying channel conditions.

U.S. Pat. No. 5,559,810 to Gilbert et al. teaches a communication system using data reception history for selecting a modulation technique from among a plurality of modulation techniques to thus optimize the use of communication resources. At least one block of data is transmitted with a particular modulation technique and a data reception history is maintained to indicate transmission errors, e.g., by keeping a value of how many blocks had errors. The data reception history is updated and used to determine an estimate of transmission signal quality for each modulation technique. This value is then used in selecting the particular modulation technique.

The system and method taught by Gilbert rely on tracking errors in the reception of entire blocks of data. In fact, signal quality statistics, e.g., signal-to-interference and noise ratio (SINR) are derived from the error numbers for entire blocks of data, which requires a significant amount of time. Thus, this method does not permit one to select rapidly and efficiently from a large number of encoding modes to adapt to varying channel conditions, especially in the event of rapid fades as encountered in mobile wireless systems.

It would be an advance to provide an appropriately organized set of modes or a mode lookup table to allow the system to rapidly and efficiently select the appropriate mode for encoding data in a quickly changing channel. It is important that such mode lookup tables be adaptable and efficient in all wireless systems, including Multiple Input Multiple Output (MIMO), Multiple Input Single Output (MISO), Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) systems as well as systems using multiple carrier frequencies, e.g., OFDM systems.

SUMMARY

The present invention provides a method of constructing a lookup table of modes for encoding data for transmission in a wireless communication channel from a transmit unit to a receive unit. In accordance with the method, at least one quality parameter of the data is selected to monitor the quality of the data as received by the receive unit. A first-order statistical parameter is then determined for the one or more quality

parameters.   Also, a second-order statistical parameter is
determined for the one or more quality parameters.   The modes
are then arranged in the lookup table based on both the first-
order and second-order statistical parameters.   The first-order
statistical parameter can be a mean while the second-order
statistical parameter can be a variance of the quality parameter
or parameters.   The first-order and second-order statistical
parameters can be determined from a simulation of the wireless
communication channel or from field measurements of the wireless
communication channel.

To further aid in the organization of modes in the lookup table,
a communication parameter is selected and a target value of the
communication parameter is set.   For example, the communication
parameter is an error rate, such as a bit error rate (BER) or a
packet error rate (PER) of the data as received by the receive
unit.   The target value of the error rate can be set in
accordance with the quality of service required.   Any specific
target value is related to the values of the first-order and
second-order statistical parameters of the one or more quality
parameters.   In other words, a mapping or correspondence exists
between the target value of the communication parameter and the
first and second-order statistical parameters of the quality
parameter or parameters.   The modes in the lookup table are
arranged based on the first and second-order statistical
parameters and the corresponding target value of the
communication parameter.

The communication parameter can also be a data capacity, signal quality, spectral efficiency, throughput or another suitable communication parameter. In fact, the communication parameter can also be a statistical measure of the quality of data transmission through the wireless communication channel. In other words, the communication parameter can be a statistical communication parameter such as mean packet error rate, mean bit error rate or the mean of any other selected communication parameter.

The quality parameter selected is conveniently a short-term quality parameter. In this case it is also convenient that the second-order statistical parameter be a variance of the short-term quality parameter. For example, the variance can be a temporal variance or a frequency variance and the short-term quality parameter can be a signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR) or power level.

During use of the lookup table the selection of modes may have to be modified depending on the actual or instantaneous condition of the wireless communication channel. That is because the lookup table is constructed based on simulation of the wireless communication channel or field measurements of the wireless channel, as noted above. The target values of the communication parameter may thus no longer correspond to the first and second-order statistical parameters in the lookup table. For this reason, the method of invention further calls for measuring a measured value of the communication parameter in the wireless channel. An adjustment is assigned to at least one

of the first- and second-order statistical parameters of the quality parameter, based on the difference between the measured value and target value of the communication parameter. The mode associated with these adjusted statistical parameters is then selected from the lookup table.

When transmitting the data at more than one frequency, it is useful to select frequency variance as the second-order statistical parameter. In particular, this should be done when employing a multi-carrier scheme, e.g., OFDMA, FDMA or CDMA in transmitting the data. Of course, the invention can also be used in TDMA and other transmission schemes not employing multi-carrier transmissions. Additionally, temporal variance of the quality parameter can also be calculated and used in adjusting the modes selection from the lookup table.

In accordance with the invention, the lookup table and instructions for its construction are stored in a suitable storage medium, e.g., a magnetic, magneto-optic or optic storage medium. Likewise, instructions are stored for selecting one or more quality parameters, determining their first- and second-order statistical parameters and arranging the modes in the lookup table based on these statistical parameters. The instructions further include selecting a communication parameter, setting its target value and arranging the modes based on the target value. During operation, adjustments in the selection of modes can be based on the difference between the measured value of the communication parameter and the target value.

A detailed description of the invention and the preferred and alternative embodiments is presented below in reference to the attached drawing figures.

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BRIEF DESCRIPTION OF THE FIGURES

Fig. 1   is a simplified diagram illustrating a communication system in which the method of the invention is applied.

10   Fig. 2   is a graph illustrating the effects of channel variation in time and frequency.

Fig. 3   is a block diagram of a transmit unit in accordance with the invention.

Fig. 4   is a block diagram of an exemplary receive unit in accordance with the invention.

Fig. 5   is a schematic diagram illustrating data transmitted in a wireless communication channel.

Fig. 6   is a flow diagram illustrating the construction of a lookup table based on first-order and second-order statistical parameters in accordance with the invention.

Fig. 7   is a simplified block diagram of a simulator.

Fig. 8   is a graph illustrating first-order and two second-order statistical parameters for three modes.

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DETAILED DESCRIPTION

The invention will be best understood after first considering the simplified diagram of Fig. 1 illustrating a portion of a wireless communication system **10**, e.g., a cellular wireless

system in which the invention can be employed. For explanation purposes, downlink communication will be considered where a transmit unit **12** (**12A, 12B**) is a Base Transceiver Station (BTS) and a receive unit **14** (**14A, 14B, 14C**) is a mobile or stationary wireless user device. Of course, the method can be used in uplink communication from receive unit **14** to BTS **12**.

Exemplary user devices **14** include mobile receive units such as a portable telephone **14A,** a car phone **14B** and a stationary receive unit **14C.** Receive unit **14C** can be a wireless modem used at a residence or any other fixed wireless unit. Receive units **14A** and **14C** are equipped with multiple antennas or antenna arrays **20**. These receive units can be used in Multiple Input Multiple Output (MIMO) communications taking advantage of techniques such as spatial multiplexing or antenna diversity. Receive unit **14B** has a single antenna **19** and can be used in Single Input Single Output (SISO) communications. It will be understood by those skilled in the art that receive units **14A, 14B, 14C** could be equipped in SISO, MISO (Multiple Input Single Output), SIMO (Single Input Multiple Output) or MIMO configurations. For example, in Fig. 1 receive unit **14B** is shown having a single antenna **19** and therefore it can be employed in SISO or MISO configurations. MISO configuration can be realized in the case of receive unit **14B,** for example by receiving signals from the antenna array at BTS **12A** or from a distinct BTS such as **12B,** or any combination thereof. With the addition of multiple receive antennas receive unit **14B,** as well as receive units **14A** and **14C,** could also be used in SIMO or MIMO configurations. In any of the configurations discussed above, the communications

techniques can employ single-carrier or multi-carrier communications techniques.

A first exemplary transmit unit **12** is a BTS **12A** equipped with an antenna array **16** consisting of a number of transmit antennas **18A**, **18B**, ..., **18M** for MIMO communications. Another exemplary transmit unit **12** is a BTS **12B** equipped with a single omnidirectional antenna **13**. BTSs **12A**, **12B** send data in the form of transmit signals TS to receive units **14A**, **14B**, **14C** via wireless communications channels **22**. For simplicity, only channel **22A** between BTS **12A** and receive unit **14A** and channel **22B** between BTS **12B** and receive unit **14C** are indicated.

The time variation of channels **22A**, **22B** causes transmitted signal TS to experience fluctuating levels of attenuation, interference, multi-path fading and other deleterious effects. Therefore, communication parameters of channel **22A** such as data capacity, signal quality, spectral efficiency and throughput undergo temporal changes. The cumulative effects of these variations of channel **22A** between BTS **12A** and receive unit **14A** are shown for illustrative purposes in Fig. 2. In particular, this graph shows the variation of a particular quality parameter, in this case signal strength of receive signal RS at receive unit **14A** in dB as a function of transmission time t and frequency f of transmit signal TS sent from transmit unit **12A**. Similar graphs can be obtained for other quality parameters, such as signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR) as well as any other quality parameters known in the art. Of the various quality parameters signal

strength (power level), SINR and SNR are generally convenient to use because they can be easily and rapidly derived from receive signals RS as is known in the art.

A mode for encoding data at transmit units **14** is selected based on a first-order statistical parameter and a second-order statistical parameter of the quality parameter. The details of the method will now be explained by referring to the operation of a transmit unit **50**, as illustrated in Fig. 3 and a receive unit **90** as illustrated in Fig. 4.

Transmit unit **50** receives data **52** to be transmitted; in this case a stream of binary data. Data **52** is delivered to a transmit processing block **56**. Transmit processing block **56** subdivides data **52** into a number k of parallel streams. Then, processing block **56** applies an encoding mode to each of the k streams to thus encode data **52**. It should be noted, that before transmission data **52** may be interleaved and pre-coded by an interleaver and a pre-coder (not shown). The purpose of interleaving and pre-coding is to render the data more robust against errors. Both of these techniques are well-known in the art.

The mode is determined by a modulation during which data **52** is mapped into a constellation at a given modulation rate, and a coding rate at which this translation is performed. For example, data **52** can be converted into symbols through modulation in a constellation selected from among PSK, QAM, GMSK, FSK, PAM, PPM, CAP, CPM or other suitable constellations.

The transmission rate or throughput of data **52** will vary depending on the modulation and coding rates used in each of the k data streams.

Table 1

Mode	Modulation Rate (bits/symbol)	Coding Rate	Throughput (bits/s/Hz)
1	2	3/4	3/2
2	2	2/3	4/3
3	2	1/2	1
4	2	1/3	2/3
5	4	3/4	3
6	4	2/3	8/3
7	4	1/2	2
8	4	1/3	4/3
9	5	3/4	15/4
10	5	2/3	10/3
11	5	1/2	5/2
12	5	1/3	5/3
13	6	3/4	9/2
14	6	2/3	4
15	6	1/2	3
16	6	1/3	2

Table 1 illustrates some typical modes with their modulation rates and coding rates and the corresponding throughputs for data **52**. The modes are indexed by a mode number so as to conveniently identify the modulation and coding rates which are to be applied to data **52** in each mode. Tables analogous to Table 1 for other coding and modulation rates can be easily derived as these techniques are well-known in the art.

Referring back to Fig. 3, a set of modes, conveniently arranged in the form of a lookup table indexed as described above, are stored in a database **78** of transmit unit **50**. Database **78** is

connected to a controller **66**, which is also connected to transmit processing block **56** and spatial mapping unit **58**. Controller **66** controls which mode from database **78** is applied to each of the k streams and it also controls the spatial mapping to be performed by spatial mapping unit **58**.

In addition to encoding the k streams, transmit processing block **56** adds training information into training tones **T** (see Fig. 5) and any other control information, as is known in the art. Thus processed, the k streams are sent to an up-conversion and RF amplification stage **70** having individual digital-to-analog converters and up-conversion/RF amplification blocks **74** through spatial mapping unit **58**. Spatial mapping unit **58** maps the k streams to M inputs of the up-conversion and RF amplification stage **70**. The M outputs of amplification stage **70** lead to corresponding M transmit antennas **72** of an antenna array **76**.

A person skilled in the art will recognize that the number M of transmit antennas **72** does not have to be equal to the number of streams k. That is because various spatial mappings can be employed in assigning streams k to transmit antennas **72**. In one mapping, a certain transmit antenna **72B** transmits one of the k streams. In another mapping, a number of transmit antennas **72** transmit the same stream k. In yet another embodiment, the k streams are assigned to M antennas **72** or a subset thereof via the spatial mapping unit **58** and unit **70**. In fact, any kind of mapping involving the use of spatial multiplexing (SM) and antenna diversity can be used.

Transmit antennas **72** transmit data **52** in the form of transmit signals TS. Fig. 5 illustrates, as will be recognized by those skilled in the art, a multicarrier transmission scheme with n frequency carriers (tones). The vertical axis illustrates frequency carriers while the horizontal axis illustrates OFDM symbol periods. Each block corresponds to one of n frequency carriers during an OFDM symbol. The blocks marked with D correspond to data and the blocks marked with T correspond to training. Fig. 5 indicates that training is performed on all tones during an OFDM training symbol. It will be clear to a person skilled in the art that a subset of these tones could be used for training and the corresponding frequency response could be computed at the receiver by interpolating.

Transmit signals TS propagate through channel **22** and there experience the effects of changing conditions of channel **22**, as described above. Transmit signals TS are received in the form of receive signals RS by a receive antenna **91A** belonging to an antenna array **92** of a receive unit **90**, shown in Fig. 4.

Again referring to Fig. 4, receive unit **90** has N receive antennas **91A**, **91B**, ..., **91N** for receiving receive signals RS from transmit unit **50**. Receive unit **90** can be any suitable receiver capable of receiving receive signals RS via the N receive antennas **92**. Exemplary receivers include linear equalizer receivers, decision feedback equalizer receivers, successive cancellation receivers and maximum likelihood receivers.

Receive unit **90** has an RF amplification and down-conversion stage **94** having individual RF amplification/down-conversion and analog-to-digital converter blocks **96** associated with each of the N receive antennas **91A, 91B, ..., 91N.** The N outputs of stage **94** are connected to a receive processing block **98** which performs receive processing to recover the k streams encoded by transmit processing block **56** of transmit unit **50.** The recovered k streams are passed on to a signal detection, decoding and demultiplexing block **100** for recovering data **52.** In the case of antenna diversity processing it should be understood that k is equal to one and thus there is only a single stream recovered.

The receive processing block **98** computes the quality parameters for each of the k streams and sends this information to a statistics computation block for computing statistical parameters of the one or more quality parameters. The method of the invention can recognize slow and rapid channel variations and allows for efficient mode selection by taking both types of variation into account. This is accomplished by taking into account at least two statistics of one or more quality parameters. Conveniently, the quality parameter is a short-term quality parameter. Suitable short-term quality parameters include signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR) and power level.

In the present embodiment the short-term quality parameter used is SINR. Statistics computation block **102** computes a first-order statistical parameter **104** and a second-order statistical parameter **106** of SINR. Conveniently, first-order statistical

parameter **104** is mean SINR and second-order statistical parameter is a variance SINR. Variance **106** of SINR actually consists of two values, SINR temporal variance **106A** and SINR frequency variance **106B**. In systems which do not employ multi-carrier transmission schemes frequency variance **106B** does not have to be computed. It should be noted that each data stream of the k streams will have an associated statistical parameter **104, 106A, 106B**.

A window adjustment **108** such as a timing circuit is connected to statistics computation block **102**. Window adjustment **108** sets a first time interval or first sampling window τ_1 (see Fig. 5) during which the SINR is sampled. Conveniently, SINR is sampled during training tones **T** occurring during sampling window τ_1.

The present embodiment uses multiple carrier frequencies f_c and thus SINR is sampled and computed by block **102** for data **52** transmitted at each of the n carrier frequencies f_c. By buffering the SINR values for all the training tones **T** during time window τ_1 statistics computation block **102** constructs the following matrix:

$$\begin{bmatrix} SINR_{1,1} & SINR_{1,2} & ... & SINR_{1,w} \\ SINR_{2,1} & ... & & \\ ... & & & \\ SINR_{n,1} & & & SINR_{n,w} \end{bmatrix}$$

where $SINR_{i,j}$ is the SINR at the i-th carrier frequency f_{ci} during training phase j. There are thus 1 to n carrier frequencies f_c and 1 to w training phases.

First-order statistical parameter **104** of short-term quality parameter, in this case mean SINR, can be expressed as:

$$SINR_{mean} = \frac{1}{n \cdot w} \sum_{i=1}^{n} \sum_{j=1}^{w} SINR_{i,j} \ .$$

Second-order statistical parameters **106A**, **106B** of short-term quality parameter, in this case SINR frequency variance and SINR temporal variance can be expressed as:

$$SINR_{var(freq)} = \frac{1}{n \cdot w} \sum_{i=1}^{w} \sum_{j=1}^{n} \left[SINR_{j,i} - \frac{1}{n} \sum_{k=1}^{n} SINR_{k,i} \right]^2 , \ \ and$$

$$SINR_{var(time)} = \frac{1}{w} \sum_{k=1}^{w} \left[\frac{1}{n} \sum_{i=1}^{n} SINR_{i,k} - \left(SINR_{mean} \right) \right]^2 .$$

In general, the duration of first sampling window τ_1 takes into account general parameters of the communication system and/or channel **22**. For example, channel **22** has a coherence time during which the condition of channel **22** is stable. Of course, the coherence time will vary depending on the motion of receive unit **90**, as is known in the art. In one embodiment, window adjustment **108** sets first sampling window τ_1 based on the coherence time. Specifically, first sampling window τ_1 can be set on the order of or shorter than the coherence time. Thus, the first- and second-order statistical parameters **104**, **106A**, **106B** computed during time window τ_1 are minimally affected by loss of coherence. In another embodiment window adjustment **108**

sets first sampling window τ_1 to be much larger than the coherence time.

Alternatively, window adjustment **108** sets first sampling window τ_1 on the order of or equal to a link update time or a delay time. This is the amount of time required for receive unit **90** to communicate to transmit unit **50** the SINR statistics and/or the appropriate mode selection based on these SINR statistics as explained below. The delay time is a design parameter limited by the complexity of computations involved and feedback from receive unit **90** to transmit unit **50**. Of course, the delay time of the system should preferably be less or significantly less than the channel coherence time. On the converse, when the delay time of the system is greater than channel coherence time the window size τ_1 should also be chosen appropriately to be larger than the channel coherence time. In any case, it should be noted that the first-order and second-order statistics of the short-term quality parameter, in the present case mean and variance of SINR, should be sampled and computed over sampling windows of the same window length.

In addition to the above computations, receive unit **90** also computes a communication parameter, in this embodiment an error rate of data **52**. For example, receive unit **90** computes a bit error rate (BER) or a packet error rate (PER) of data **52**. It typically takes a much longer period of time than the length of first sampling window τ_1 to compute these error rates. Conveniently, these error rates are thus computed during second sampling window τ_2 or over an error rate computation time (see

Fig. 5). The computation of these error values and circuits necessary to perform these computations are well known in the art.

5   It should be noted that first-order and second-order statistics of the communication parameters should be sampled over just one window length, i.e., second sampling window τ_2. In the present embodiment only first-order statistic of the communication parameter, mean PER is computed during second time window τ_2. As

10   is well known in the art, the packet error rate can be computed by keeping track of the cyclic redundancy check (CRC) failures on the received packets. PER computation is a well-known technique and is performed in this embodiment by a PER statistics circuit **110**. The PER computation can be used to

15   further improve mode selection from the lookup table of the invention by providing correction factors or adjustments, as described below.

The first- and second-order statistical parameters of the short-term quality parameter **104, 106A, 106B** are delivered from

20   statistics computation block **102** to a mode selection block **112**. Mode selection block **112** is connected to a database **114**, conveniently containing the same modes as database **78** of transmit unit **50**. The set of modes in database **114** is related

25   to first-order statistical parameter **104** and second-order statistical parameters **106A, 106B** of short-term quality parameter. When used, PER statistics circuit **110** is also connected to database **114** and delivers the PER statistics to it.

Block **112** selects the subsequent mode number for encoding data **52**. Block **112** is connected to a feedback block **116** and a corresponding transmitter **118** for transmission of the feedback to transmit unit **50**. Here the convenience of indexing modes becomes clear, since feedback of an index number to transmit unit **50** does not require much bandwidth. It should be noted, that in the present embodiment a mode selection is made for each of the k streams. In other words, a mode index indicating the mode to be used for each of the k streams is fed back to transmit unit **50**. In another embodiment, it may be appropriate to send a mode difference indicating how to modify the current mode for subsequent transmission. For example, if the current transmission is mode 1, and the mode index of the subsequent mode is 3, the mode difference would be 2. In yet another embodiment, it may be suitable to send the channel characteristics back to transmit unit **50**. In this case the computation of statistics of the quality parameter and the mode selection are performed at transmit unit **50**.

Referring back to Fig. 3, transmit unit **50** receives feedback from receive unit **90** via a feedback extractor **80**. Feedback extractor **80** detects the mode index or any other designation of the selected modes for each of the k streams and forwards this information to controller **66**. Controller **66** looks up the mode by mode index in database **78** and thus determines the modulation, coding rate and any other parameters to be used for each of the k streams. In the event of using time-division duplexing (TDD), which is a technique known in the art, the quality parameters can be extracted during the reverse transmission from receive

unit **90** or remote subscriber unit and no dedicated feedback is required.

In one embodiment, when the system of invention is placed into operation, transmit processing block **56** first assigns an initial mode, e.g., one of the modes available in the set of modes stored in database **78** to each of the k streams. The choice of initial modes can be made on previously known data, simulations or empirical results. Transmit unit **50** then transmits data **52** in the form of transmit signals TS to receive unit **90**.

Receive unit **90** receives receive signals RS, reconstructs data **52** therefrom, and computes first-order and second-order statistical parameters **104, 106A, 106B** of short-term quality parameter. Mode selection block **112** then selects from database **114** the subsequent mode based on parameters **104, 106A, 106B**.

In accordance with the present invention, the modes from which the initial mode and subsequent modes are chosen are arranged in a lookup table of modes constructed based on first-order and second-order statistical parameters of at least one of the quality parameters indicating the quality of data **52** at receive unit **90**. In the present embodiment the first-order and second-order statistics of SINR are used to construct the lookup table.

The flow diagram in Fig. 6 illustrates two ways of constructing and using the lookup table. In a common first step **200** the communication system characteristics are defined. In the present embodiment, these parameters include the number M of

transmit antennas **72**, the number N of receive antennas **91**, the type of mapping of the k streams to transmit antennas **72** performed by spatial mapping unit **58** and the polarizations of antennas **72**, **91**. In some cases additional characteristics relating to transmit and receive processing of data **52** should also be specified. In fact, any communication system characteristics which affect the relationship between the first-order and second-order statistical parameters, in this case SINR mean and SINR variance, and the communication parameter, in this case mean PER, should be included as communication system characteristics.

In a second step **202** the parameters of channel **22** are selected. These parameters are related to the environment (e.g., rural, urban or suburban) in which the communication system is deployed. The parameters of channel **22** can include correlations of receive antennas **91**, correlations of transmit antennas **72**, Doppler spread, delay spread, Rician k factor, cross pole discrimination values and any other parameters which help to predict the behavior of channel **22**.

In a third step **204** selected parameters of channel **22** and the system characteristics are used to select a group of modes which can be used by the system. In the present embodiment, it is convenient to select all modes which can be differentiated or ordered by their first- and second-order SINR statistics and first-order PER statistics. This group can be limited to a subset of modes which are likely to yield good transmission performance. For example, one can select from the group of all

modes those which promise to yield good performance given channel **22** and system characteristics. In particular, one can select modes which promise to maximize a communication parameter or combination of communication parameters such as BER, PER, data capacity, signal quality, spectral efficiency and throughput. It is important to select a set of modes with different radio interface rates (spectral efficiency) and robustness, so that each mode is optimal for use in different link quality regions. In this way, there is a mode available for the various likely conditions of channel **22**. As is well-known in the art, spectral efficiency is a function of the modulation used, and robustness is a function of the coding rate used.

The first alternative in constructing the lookup table involves simulation of system operation rather than empirical testing. In other words, in constructing the lookup table first-order and second-order statistical parameters can be determined from a simulation of the wireless communication channel or from field measurements of the wireless communication channel. In the former case the answer in step **206** is "no" and in the subsequent step **208** a system simulator is set up. The simulator is based on system characteristics defined in step **200** and parameters of channel **22** defined in step **202**.

A simplified block diagram of a simulator **230** is shown in Fig. 7. Data **52** is processed by simulator **230** to simulate transmission from transmit unit **50** via channel **22** to receive unit **90**. The output of simulator **230** is data **52** as recovered by

receive unit **90**, i.e., data **52** with errors. A statistics computation block **232** connected to simulator **230** calculates the error statistics of data **52**. Additionally, statistics computation block **232** computes first-order and second-order statistical parameters of the at least one quality parameter, in this case SINR mean and variance. Also, statistics computation block **232** conveniently computes the communication parameter, in this case mean PER, which represents a statistical communication parameter.

Referring back to the flow diagram of Fig. 6, the first- and second-order statistical parameters computed by block **232** are obtained in step **210**. In the second alternative to constructing the lookup table the answer in step **206** is "yes" and empirical or field testing is performed in step **212** on data **52** transmitted through channel **22** in the actual system to determine the first- and second-order statistical parameters. Again, the first-order and second-order statistical parameters of SINR are determined, and, conveniently, the statistical communication parameter in the form of mean PER is also determined in step **212**.

The statistical parameters derived either from the actual system in step **212** or from simulation in step **210** are used to select and arrange the modes in a lookup table in step **214**. An exemplary lookup table for the present embodiment is shown below. It should be noted that for the purposes of this description, the below system of cross-referenced tables or sub-tables is considered to represent the lookup table.

Sub-Table 1

SINR variance (frequency)	SINR variance (temporal)	Sub-Table to use
0 dB	0 dB	A
0 dB	5 dB	B
0 dB	10 dB	C
0 dB	15 dB	D
0 dB	20 dB	E
5 dB	0 dB	B
5 dB	5 dB	C
5 dB	10 dB	D
5 dB	15 dB	E
5 dB	20 dB	F
10 dB	0 dB	C
10 dB	5 dB	D
10 dB	10 dB	E
10 dB	15 dB	F
10 dB	20 dB	F
15 dB	0 dB	D
15 dB	5 dB	E
15 dB	10 dB	F
15 dB	15 dB	F
15 dB	20 dB	F
20 dB	0 dB	E
20 dB	5 dB	F
20 dB	10 dB	F
20 dB	15 dB	F
20 dB	20 dB	F

Sub-Table C

PER mean	SINR mean	Mode
1%	0 dB	mode i
2%		mode j
3%		mode k
4%		mode l
≥5%		mode m
1%	2 dB	mode j
2%		mode k
3%		mode l
4%		mode m
≥5%		mode n
1%	4 dB	mode k
2%		mode l
3%		mode m
4%		mode n
≥5%		mode o
1%	6 dB	mode l
2%		mode m
3%		mode n
4%		mode o
≥5%		mode p
1%	8 dB	mode m
2%		mode n
3%		mode o
4%		mode p
≥5%		mode r
. . .	. . .	. . .

Sub-tables 1 and C illustrate a portion of the lookup table in which modes are arranged to conveniently determine the mode to be used in encoding data **52** based on the frequency and temporal variance of SINR (second-order statistical parameters of short-term quality parameter), mean SINR (first-order statistical parameter of short-term quality parameter) and mean PER (statistical communication parameter). Sub-Table 1 is

referenced to   tables A, B, C, D, E and F (only Sub-Table C
shown) based on frequency and temporal variances **106A, 106B** of
SINR.

For example, the third entry in Sub-Table 1 corresponds to
situations where SINR frequency and temporal variances are 0 dB
and 10 dB respectively. In this situation Sub-Table C is used
in further mode selection. Sub-Table C is organized by the
statistical parameter or mean PER and mean SINR (first-order
statistical parameter of short-term quality parameter). The
mean PER values are actually target values. The quality of
service required usually dictates the target value. For
example, in high-quality data transmissions the target value is
set very low, while in lower quality voice transmissions a
higher target value is set.

The modes in the lookup table are arranged based on the first
and second-order statistical parameters and the corresponding
target value of the communication parameter. The target values
of PER are related to mean SINR in Sub-Table C and to frequency
and temporal variances of SINR in Sub-Table 1. In other words,
a mapping or correspondence is established in the lookup table
between PER target values and the first and second-order
statistical parameters of the quality parameter. Each of these
mappings has associated with it a corresponding mode to be used
in encoding data **52**, here indicated as modes i,j,...r.

Once arranged in the manner described, the lookup table is ready
for use. The quality of service (QoS) is defined in terms of

the target value for mean PER at which the requisite user services (e.g., voice communication) can be supported. When the conditions of channel **22** and of the communication system are close to those simulated or obtained in field test the lookup table can be used directly to select the appropriate mode corresponding to the target PER and SINR statistics. More commonly, however, the selection of modes may have to be modified depending on the actual or instantaneous condition of the wireless communication channel **22** or changes to the communication system. Again, this is because the lookup table is constructed based on a finite number of simulation samples, or using particular channel models, or using field measurements of a particular wireless channel, as noted above. The mean PER target values may thus no longer correspond to the mean SINR and SINR frequency and temporal variances as mapped in the lookup table.

Once the lookup table is created, it is stored in database **114** (or in both databases **114** and **78**) and the system is deployed in the field. Because the lookup system was created with a finite number of simulation samples or using particular channel models, there is a possibility that the mapping it contains between the SINR statistical parameters and the target value of PER becomes inaccurate, once deployed in the field. The mapping is conveniently corrected or modified based on the difference between the target value of PER and the measured value of PER in actual operation. For this purpose it is convenient to define an accuracy bound or interval about the target value of PER. For example, when the target value of PER is 3%, the interval

may be defined between 2.5% and 3.5%. When the measured value of PER goes above the upper bound of the interval, i.e., $PER_{meas} > 3.5\%$, then a positive correction factor or adjustment δ is applied to the required SINR levels in the lookup table. On the other hand, when the measured value of PER goes below the lower bound of the interval a negative adjustment $-\delta$ is applied to the required SINR levels in the lookup table. After a few rounds of PER measurements the lookup table is thus automatically adjusted to the particular field channel parameters and now provides accurate short term mode selection. This adjustment of the lookup table is indicated in step **216** in the diagram of Fig. 6. As noted above, the measurement of PER can be performed by PER statistics circuit **110**.

Of course, the communication parameter does not have to be PER. In another embodiment, the lookup table is built up on a mapping between BER and SINR statistics. The structure of the lookup table is analogous to the one described above where PER and its target value were used in mode selection.

Fig. 8 is a graph illustrating BER versus first-order statistics of short-term quality parameter (SINR mean) for a given second-order statistics of the short-term quality parameter (SINR variances). It is understood that a complete set of such curves is provided for different values of second-order statistics of SINR. Only three modes i, j, k are shown for reasons of clarity, but it is apparent that all modes in the lookup table should be examined. Specifically, the target value of BER set is indicated in the graphs by BER by cut-off line **240**. The

measured value of mean SINR in channel **22** is indicated by upper bound **242**. Based on the mean SINR versus BER curves only mode k is able to support the required BER. In fact, this approach of studying the performance of the communication parameter as a function of SINR statistics, including the remaining frequency and temporal variances, is a convenient method which a person of average skill in the art will be able to use in the construction of the lookup table.

Once the lookup table is constructed and organized as described above it is most conveniently stored in databases **114** and **78**. The lookup table will not change with time because of changing conditions of channel **22**; rather adjustments δ will allow the user to adjust the lookup table to its particular field channel parameters. It is also convenient to store the above-described steps for constructing and organizing the table. For example, the steps or method of constructing and organizing the lookup table can be stored in the form of a computer-implemented program in the same storage medium as the lookup table itself in database **117** or **78** or both. Alternatively, mode selection block **112** can contain the program in its memory. In yet another embodiment, the program can reside in controller **66** of transmit unit **50**.

During operation mode selection block **112** takes advantage of the lookup table in determining and assigning the modes to each of the k streams. These mode selections are fed back to transmit unit **50** and applied to the k streams. The operation repeats itself, and each new selection of subsequent modes is fed back

to transmit unit **50** to thus account for the changing conditions of channel **22**.

A person skilled in the art will recognize that numerous alternatives exist to the embodiments described above. For example, the communication parameter can be a data capacity, signal quality, spectral efficiency, throughput or another suitable communication parameter. In fact, the communication parameter can be any suitable statistical measure of the quality of data transmission through the wireless communication channel. The method and system of invention can be used to construct lookup tables of modes useful in any data transmission technique such as OFDMA, FDMA, CDMA, TDMA.

It will thus be clear to one skilled in the art that the above embodiments may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.